# Hydrokinetics Power Systems in Massachusetts

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## I. Hydropower

Hydropower is the dominant form of renewable energy available in the U.S. today and an essential component of our electrical infrastructure. Hydropower refers to using the energy in flowing water to power mechanical systems, such as a mill for grinding grain, or to produce electricity. The term hydropower is often used to refer to both hydroelectric and hydrokinetic power systems. In both systems, the energy in flowing water causes a turbine to spin. The turbine is connected to a generator which also begins to spin, creating an electric current[1].

The majority of hydropower in the U.S. is produced at traditional hydroelectric power plants (see DEP pamphlet on hydropower). Hydropower facilities rely on both head and flow of water to generate electricity, whereas hydrokinetic relies only on flow. The three main types of hydroelectric power systems are impoundment, pumped storage, and diversion. In impoundment systems, water is blockaded behind a dam and then funneled through a channel or penstock to a turbine and generator. In pumped storage systems, water is pumped up to a reservoir during periods of low electricity demand and then directed from the reservoir to the turbine during periods of high electricity demand. In diversion or "run of the river" systems, a portion of the water in a river is diverted temporarily to flow through a turbine but is returned to the river after electricity has been generated.

## II. Hydrokinetics

Hydrokinetic turbines only require flow to produce electricity, and therefore they are suitable for a wide variety of situations. The hydrokinetic generators discussed herein are able to produce electricity from tidal and ocean currents, river flow, or from the motion of waves. Hydrokinetic technologies are rapidly evolving but the striking diversity of designs currently under development can be characterized by several general categories relative to wave generators on one hand, and tidal, ocean current, and river current on the other.

### A. Wave

Ocean waves are formed by wind passing over open water. Since wind is caused by solar heating, the energy stored in waves can be considered a form of solar energy.[2] The general types of technologies under development may be categorized by the method by which the generator intercepts wave energy, as described below[3].

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[1] "How Hydropower Works." *Eere.energy.gov*. Office of Energy Efficiency and Renewable Energy, US DOE. 30 Aug. 2005. Web. 20 July. 2009.
[2] Duckers, Les (2004) "Wave Energy" in Boyle, Godfrey (ed) Renewable Energy: Power for a Sustainable Future. Oxford University Press, New York.
[3] Descriptions of wave generating devices are taken from: United States Minerals Management Service (2006), "Technology White Paper on Wave Energy Potential on the U.S. Outer Continental Shelf." Downloadable at http://ocsenergy.anl.gov;

i. Terminators- Extend perpendicular to the direction of wave travel and physically intercept the wave. Typically sited close to shore, but offshore applications are being developed. The oscillating water column is a form of terminator in which water from a wave enters a chamber, forcing the air in the chamber through an opening connected to a turbine.
ii. Attenuators- In contrast to terminators, attenuators extend parallel to the direction of the wave so that its energy is drawn toward the device as the wave moves past. These are floating devices tethered in an offshore location, and feature long, segmented structures. Ocean waves cause flexing of the joints at where the segments connect, which drive hydraulic pumps or other converters.
iii. Overtopping devices- These may be floating offshore devices, or tapered channel ("tapchan") systems fixed on a shoreline, that direct waves into a reservoir, building a head that then drives a turbine as water in the reservoir drains back into the ocean.
iv. Point absorbers- These convert wave energy at a single point by using the rise and fall of the wave. A typical example is a tethered buoy system with one relatively fixed component and another that is driven up and down by wave motion, and the relative motion drives an electromechanical or hydraulic energy converter. An example of this type of device was tested in early 2009 off the coast of Newburyport by Resolute Energy. The device generates electricity by using wave motion to move magnets through a coil of wires[4].

B. Ocean, Tidal, and River current[5]

Hydrokinetic devices utilizing river, tidal or ocean currents are considered together and use similar technological principles. Ocean currents may be produced either by tidal effects amplified by water flow through natural narrow channels on the seabed or at the surface, or by complex large-scale processes that produce ocean streams such as the Gulf Stream. The tidal stream devices which utilize these currents are broadly similar to submerged wind turbines and are used to exploit the kinetic energy in tidal currents. Due to the higher density of water, this means that the blades can be smaller and turn more slowly, but they still deliver a significant amount of power. To increase the flow and power output from the turbine, concentrators (or shrouds) may be used around the blades to streamline and concentrate the flow towards the rotors. Four main types of tidal energy converters have been identified:[6]

i. Horizontal axis turbines- These devices are mounted on the seafloor, and function similarly to wind turbines, with the axis parallel to the flow of water.
ii. Vertical axis turbines- These devices extract energy from currents in the same manner as horizontal axis turbines, but the axis is perpendicular to the flow. Helical turbines are included in this category.
iii. Oscillating hydrofoil- This device includes a hydrofoil mounted on an arm that is lifted and dropped as the wing is affected by tidal flows, and this motion is used to drive a generator
iv. Venturi effect- Turbines mounted in a funnel-like duct, which concentrates flow.

## III. Status of Hydrokinetic Power Generation and Prospects for Massachusetts

Hydrokinetic power generation is an emerging field globally and in the U.S. in particular. The first commercial hydrokinetic project in the U.S., a set of river current turbines suspended from a barge, was completed in January

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U.S. Department of Energy web site http://www.energysavers.gov/renewable_energy/ocean/index.cfm/mytopic=50009 (accessed 10/29/09); and Duckers (2004) ibid.
[4] "Buoy to test feasibility of wave energy" Newburyport Daily News, January 13, 2009.
[5] Tidal energy devices that rely on dams or barrages are not considered here.
[6] European Marine Energy Centre (EMEC) web site, www.emec.org.uk, accessed October 27, 2009.

of 2009 in Minnesota by Hydro Green Energy, LLC[7]. Only one other license has been issued by FERC, for the construction and operation of a wave generation pilot facility off the coast of Washington state, but the license has been voluntarily surrendered by the Licensee[8]. Over 150 Preliminary Permits have been issued by FERC.[9] While these three-year permits do not authorize construction, they serve as placeholders until a full license application is submitted and therefore indicate that a site may have the necessary conditions for hydrokinetic generation. Most of these preliminary permits have been issued for potential projects along the Mississippi and Missouri Rivers, the Northwestern coast, and the New England coast. In Massachusetts, three hydrokinetic power projects have received FERC preliminary permits. These projects include two by the Natural Currents Energy Ser, LLC., one in the Cape Cod Canal and one near Cuttyhunk/Elizabeth Islands, and a project by the Town of Edgartown in Nantucket Sound. A complete list of projects that have received preliminary permits can be found under "Hydropower-Hydrokinetics" on the FERC website at http://www.ferc.gov/industries/hydropower/indus-act/hydrokinetics.asp.

The Massachusetts Ocean Management Plan, through the authority of the Massachusetts Oceans Act signed into lay in May, 2008 provides siting guidance for hydrokinetic facilities in Massachusetts offshore waters in the area beginning 1/3 mile from shore to the seaward boundary of state jurisdiction. The Ocean Management Plan concluded that, while the waters of Massachusetts offer potentially significant sources of energy, the state has only limited potential for tidal and wave energy development with existing technology.[10] A study conducted by the Electric Power Research Institute (EPRI)[11] identified six potential sites in Massachusetts that have flood and ebb peak tidal velocities averaging at least 3 knots, however only two, including the Muskegat Channel site for which a preliminary permit has been issued by FERC, has sufficiently high power density to support a commercial-scale project. In addition, a study prepared for the Massachusetts Department of Energy Resources and Massachusetts Technology Collaborative[12] found that wave energy technology is at an early stage of development. The report estimated the future technical potential of wave energy at approximately 100 MW, with an additional 80 MW potential for tidal.

## IV. Process & Regulations

As with hydroelectric power, there are many aspects to consider before installing hydrokinetic devices and the associated supports and transmission lines. In addition to the points listed above, the special considerations for flowing waters include:

- **Would installing hydrokinetic turbines have an impact on human use of the water for recreation, transportation, or fishing?**
- **Would installing hydrokinetic turbines have an effect on organisms and habitat features within the local ecosystem, such as fish that may be caught in the turbine?**

The first stop for regulatory, design, and project advice is generally to consult with appropriate regulatory agencies through a pre-application meeting. Local Conservation Commissions and MassDEP will arrange for these free meetings to help with initial design and concept decisions. The regulations surrounding turbines that will be installed in flowing water and wetlands are more involved than those for turbines installed in existing

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[7] "First Commercial Hydrokinetic Power Turbine Installed; DOE Unveils Hydropower Database." *RenewableEnergyWorld.com.* Renwable Energy World. 6 Jan 2009. Web. July 2009.

[8] FERC website, "Hydrokinetic Projects - Issued and Pending Licenses " at http://www.ferc.gov/industries/hydropower/indus-act/hydrokinetics/licences.asp. Accessed October 27, 2009.

[9] FERC web site, http://www.ferc.gov/industries/hydropower/indus-act/hydrokinetics/permits-issued.xls. Accessed November 3, 2009

[10] "Massachusetts Ocean Management Plan" (December 2009), available with technical reports at http://www.mass.gov/?pageID=eoeeasubtopic&L=3&L0=Home&L1=Ocean+%26+Coastal+Management&L2=Massachusetts+Ocean+Plan&sid=Eoeea

[11] Electric Power Research Institute (2006). "Massachusetts Tidal In-stream Energy Conversion (TISEC): Survey and Characterization of Potential Project Sites"

[12] Navigant Consulting, Inc. (2008) "Massachusetts Renewable Energy Potential"

pipes (as described above, under hydroelectric power). Hydropower projects may be subject to the requirements of some of the federal and state regulatory programs listed below.

- The Federal Energy Regulatory Commission (FERC) regulates at the national level and requires environmental impact assessments and licenses, with some exemptions for smaller installations at existing facilities[13].
- Hydrokinetic facilities and associated transmission cables on the Outer Continental Shelf (OCS) beyond state waters also require a lease from the Minerals Management Service (MMS).[14]
- The Army Corps of Engineers issues permits under section 404 of the Federal Clean Water Act for projects that place dredged or fill materials in waters of the United States and associated wetlands.
- Dredging and placement of structures in navigable waters is regulated under Sec. 10 of the Rivers and Harbors Act.
- Any hydropower facility proposed in the ocean must be consistent with the Massachusetts Ocean Management Plan, developed under the direction of the Oceans Act. The Ocean Management Plan has identified areas where renewable energy facilities may be placed and developed performance standards for their siting, construction, and operation.
- MassDEP certifies that projects allowed by a federal dredge or fill permit (issued under section 404 of the Clean Water Act) will not violate state Water Quality Standards (section 401 Water Quality Certification)
- Alteration of state defined Wetland Resource Areas are permitted through local Conservation Commissions and MassDEP implementing the state Wetlands Protection Act.
- Chapter 91 – The Public Waterfront Act regulates activities in tidelands, great ponds and certain river segments of the commonwealth.
- The Massachusetts Water Management Act – may apply if withdrawals of large volumes of water are involved in the project.[15]

## V. More Information and Financial Incentives

In addition to reduced operational costs, there are many financial incentives for the development and operation of hydroelectric power within Massachusetts. National agencies, such as the Department of Energy and EPA, and state agencies, such as the Massachusetts Clean Energy Center (MassCeC), offer grants and loans for the construction of new hydropower facilities. Complete listings are available on several online databases, including the Database for State Incentives for Renewable Energy (www.dsireusa.org)[16] and the Office of Energy Efficiency and Renewable Energy (www.eere.energy.gov/). Some of the informative websites, databases, and incentives are listed below.

### Federal Resources and Financial Incentives

- **Hydropower technologies**, visit the "Wind and Hydropower Technologies Program" site of the Office of Energy Efficiency and Renewable Energy of the U.S. Department of Energy, at www.eere.energy.gov.
- **Energy Information Association of the U.S. Department of Energy** has information on the use of energy, electricity, and hydropower in the U.S. at www.eia.doe.gov/.

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[13] "Hydropower." *FERC.gov*. Federal Energy Regulatory Commission. 8 July 2009. Web. 20 July 2009.

[14] Both FERC and MMS have jurisdiction over hydrokinetic energy facilities on the OCS. The specific roles and authority of each agency are described in an MOU between the Department of Interior and FERC (see http://www.mms.gov/offshore/RenewableEnergy/PDFs/DOI_FERC_MOU.pdf).

[15] "Water, Wastewater, and Wetlands: Regulations and Standards." *Mass.gov/DEP*. Massachusetts Department of Environmental Protection. n.d. Web. 20 July 2009

[16] "Massachusetts: Incentives/Policies for Renewable Energy." *DSIRUSAE.org*. Database of State incentives for Renewable Energy. N.C. Solar Center/ N.C. State University. 2009. Web 20 July 2009.

- **U.S. Minerals Management Service** (MMS) was granted a role in authorizing offshore renewable energy projects by the federal Energy Policy Act of 2005. MMS's web site has information on their offshore renewable program at www.mms.gov/Offshore/RenewableEnergy/index.htm
- The **Federal Energy Regulatory Commission** (FERC) regulates hydropower projects, including hydrokinetics, and has information on its hydrokinetics program at www.ferc.gov/industries/hydropower/indus-act/hydrokinetics.asp
- **REC (Renewable Energy Certificates):** Micro-hydro facilities may be able to earn extra revenue for their renewable energy through RECs. The revenue comes from the premium some consumers will pay in order to claim the renewable energy component of all of the energy within the grid. Renewable energy generators are typically paid a few cents per kilowatt-hour by their utility. More information can be found on the EPA website at http://www.epa.gov/grnpower/gpmarket/rec.htm.
- **CREB (Clean Renewable Energy Bonds):** Interest free loans in the form of tax credit bonds are available for renewable energy projects, as established by the Energy Policy Act of 2005. These bonds can be issued by public power systems and electric cooperatives. A complete description of CREB can be found at http://www.house.gov/jct/x-60-05.pdf.
- **Renewable Energy Production Credit** has incentive for the production of renewable energy from waste. Visit http://www.epa.gov/osw//hazard/wastemin/minimize/energyrec/rpsinc.htm.
- The U. S. Department of Energy recently created a database of hydrokinetic projects, http://www1.eere.energy.gov/windandhydro/hydrokinetic/default.aspx

<u>**Massachusetts Based Resources and Financial Incentives**</u>

- **MassDEP** water programs and regulations, at http://www.mass.gov/dep/water/
- **MassDEP Energy Management Pilot Program** with energy projects at drinking water and wastewater facilities in Massachusetts, at http://www.mass.gov/dep/water/wastewater/empilot.htm.
- **MassCeC (Massachusetts Clean Energy Center)**: A public agency that assists the development of the innovation sector of the state's economy and renewable energy projects. General information on hydrokinetics is available at www.masstech.org/cleanenergy/wavetidal.htm. Many different grants are available for renewable energy projects at various stages—from the feasibility study to the design and construction phase. Funding comes from the John Adams Innovation Institute and the Renewable Energy Trust. The **Large Onsite Renewables Initiative (LORI)** grant is particularly applicable to micro-hydro projects. For more information visit the MassCeC website at http://www.masscec.com
- **The State Revolving Loan Fund** provides low interest loans for drinking water and wastewater facility projects. Visit http://www.mass.gov/dep/water/wastewater/wastewat.htm
- **Renewable Energy Trust and Greenhouse Gas Emission Credits**, visit http://www.mass.gov/dep/energy.htm.

<u>**Commercial Incentives and Support**</u>

- **Net Metering:** A system that allows operators of renewable energy facilities to receive credit from their utility company for the excess electricity they produce. In most cases the credit is paid per kWh at market rates and carries over from moth to month over one billing year. The Massachusetts Department of Public Utilities differentiates actual policies on net metering by type (public, private, residential, etc.) and size class. Class I is less than 60kW, Class II is between 60kW and 1MW, and Class III is between 1 MW and 2MW. All public electric utilities are now required by the Energy Policy Act of 2005 to have net metering available upon request.

- **Energy Audits:** Most electricity providers and utility companies are capable of providing energy audits. The audit shows how electricity is being used onsite and ways to reduce energy consumption.

More information is available on the Database for State Incentives for Renewables and Efficiency website, http://www.dsireusa.org/index.cfm?EE=0&RE=1.

## VI. Hydropower Technical and Professional Associations

**New England Marine Renewable Energy Center** (MREC) at the University of Massachusetts- Dartmouth "is an organization comprised of academia, government agencies, industry, municipalities, public interest groups and concerned individuals. MREC's focus is to foster the development of ocean based renewable energy (wave, tidal, current and ocean wind). MREC is developing a network of technology developers and energy users who will collectively define the needs of this nascent industry and work to bring together the required technology, capital, infrastructure, human resources to implement ocean renewable energy in the most sustainable manner for the region." www.mrec.umassd.edu

**Ocean Renewable Energy Consortium** (OREC) "is the only national trade association exclusively dedicated to promoting marine and hydrokinetic energy technologies from clean, renewable ocean resources. Our organization embraces a wide range of renewable technologies, including wave, tidal, current, offshore wind, ocean thermal, marine biomass and all other technologies that utilize renewable resources from oceans, tidal areas and other unimpounded water bodies to produce electricity, desalinized water, hydrogen, mariculture and other by products." www.oceanrenewable.com

**Electric Power Research Institute** (EPRI) "conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies."
Web Site: http://my.epri.com/portal/server.pt? Also see page devoted to ocean energy at http://oceanenergy.epri.com

**National Hydropower Association** "Founded in 1983, NHA represents 61percent of domestic, non-federal hydroelectric capacity and nearly 80,000 megawatts overall in North America. Its membership consists of more than 140 organizations including public utilities, investor owned utilities, independent power producers, equipment manufacturers, environmental and engineering consultants and attorneys." *www.hydro.org*

**Northeast Sustainable Energy Association** "The Northeast Sustainable Energy Association (NESEA) is the nation's leading regional membership organization promoting sustainable energy solutions….For more than thirty years, NESEA has supported and inspired a growing network of professionals and sustainable energy advocates committed to responsible energy use. NESEA is committed to advancing three core elements: sustainable solutions, proven results and cutting-edge development in the field." *www.NESEA.org*

**US Hydropower**

"**US Hydropower** is a trade association representing hydropower issues in the global market. The organization is a member run council with industry leaders working to provide input to global hydropower development strategies. US Hydropower provides a point of contact for the U.S. and foreign governments reaching out to the U.S. hydropower industry."

(“Additional Resources.” *www.hcipub.com*. PennWell Hydro Group. 2009)

The web site also has a page dedicated to wave and tidal energy at: www.hydroworld.com/index/Industry_News/ocean-tidal-streampower.html

## VII. Definitions and Information.[17]

- Btu (British thermal unit): The amount of heat it takes to raise one pound of water at 39 degrees Fahrenheit by one degree.
- Capacity: The maximum amount of electricity that a micro-turbine can supply, usually given in Kilowatts or Megawatts.
- cfs (cubic feet per second): A measurement used to describe the flow rate of moving water.
- Head: The elevation difference between the water source and the turbine (also taking the weight of the water into account). An indication of the potential energy stored in the elevated water. Head is often measured either in feet or with a pressure gauge in psi (pounds per square inch).
- Net Head: The head available to a turbine after losses due to friction and other factors have been subtracted from the gross head.
- kW (Kilowatt): A unit of electrical power equivalent to 1,000 watts (1.34 horsepower)
- kWh (Kilowatt-hour): The amount of electrical energy supplied over one hour by one kilowatt of power—the same as 3,412 Btu. As a point of comparison, the Energy Information Administration cites the average U.S. household use of electricity as 936 kWh in 2007.
- Micro-hydro: hydroelectric installations that are generally below 100 kW in capacity and do not significantly disrupt the surrounding water flow.
- Psi (pounds per square inch): A measurement used to describe the flow rate of moving water, based on pressure.
- Turbine: Converts mechanical energy into electrical energy in conjunction with a generator. The primary types are impulse or reaction turbines.

[17] References for "Definitions":
Energy Information Administration: Official Energy Statistics from the US Government. Glossary. 2009. 03 Jul. 2009 <http://www.eia.doe.gov/glossary/glossary_t.htm>

"**Reaction turbine**." Encyclopædia Britannica. 2009. Encyclopædia Britannica Online. 03 Jul. 2009 <http://www.britannica.com/EBchecked/topic/492767/reaction-turbine>.

"**Impulse turbine**." Encyclopædia Britannica. 2009. Encyclopædia Britannica Online. 03 Jul. 2009 <http://www.britannica.com/EBchecked/topic/492767/reaction-turbine>.

"Micro-hydro." The Ashden Awards for Sustainable Energy. 2008. Ashden Awards Onlin. 03 Jul. 2009 <http://www.ashdenawards.org/micro-hydro>